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Market Potential for Microturbines in South Asia

An Initial Assessment For Maldives & Sri Lanka

Nexant

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MARKET POTENTIAL FOR MICROTURBINES IN SOUTH ASIA

AN INITIAL ASSESSMENT FOR MALDIVES & SRI LANKA

For

United States Agency for International Development

Under

South Asia Regional Initiative for Energy

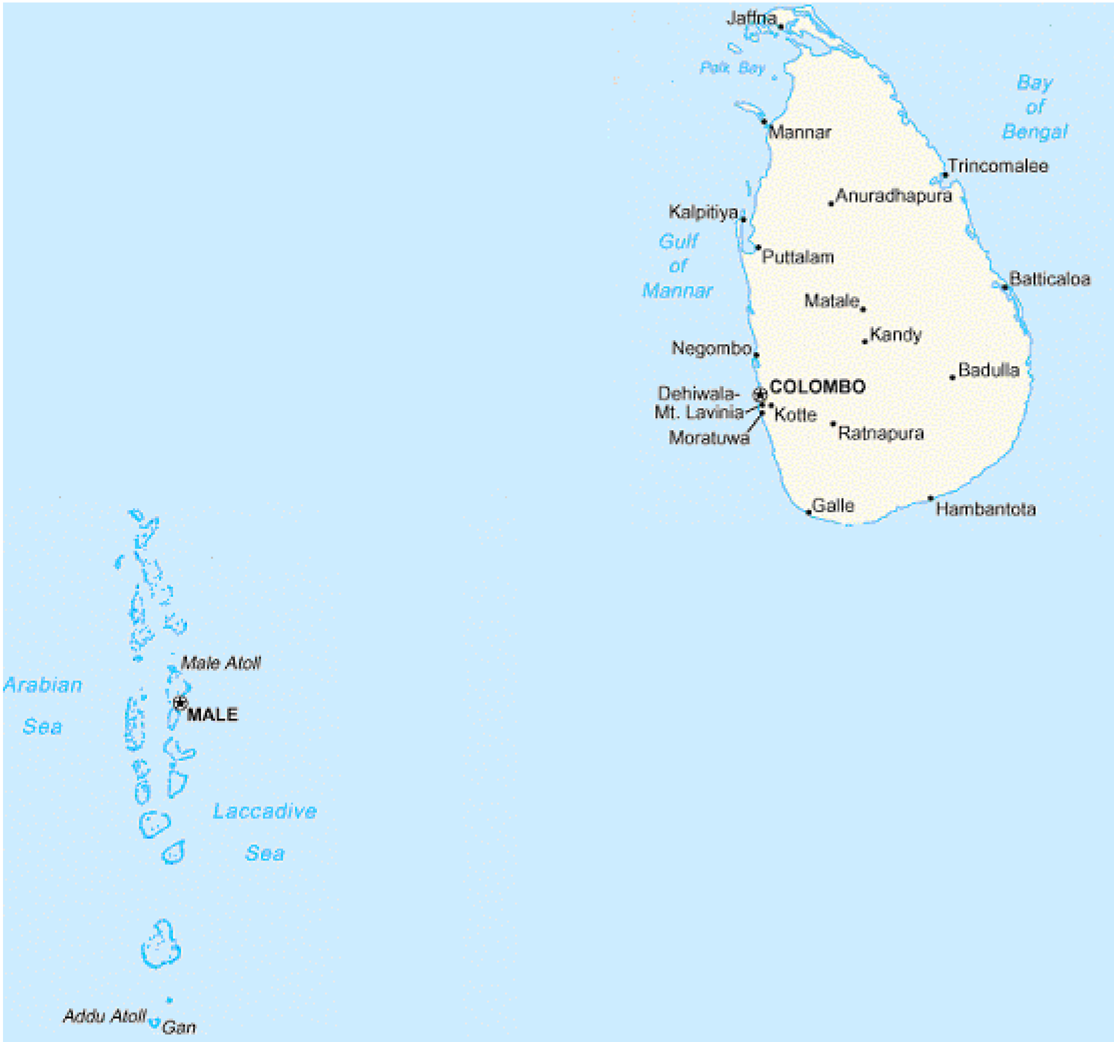
Prepared by
NEXANT SARI/Energy

Contents

Executive Summary

The U.S. Agency for International Development (USAID) initiated this study with the primary objective of determining if microturbines can provide a solution to the problem of poor access to electricity in sparsely populated remote areas and un-served urban areas in South Asia, especially in the context of Maldives and Sri Lanka. The findings that emerged from the study are summarized below:

- Microturbines can play a major role in electrifying rural areas and some selected urban areas in Maldives and Sri Lanka. Electricity demand for these segments is approximately of the order of 600 MW in Sri Lanka and 10 MW in Maldives



Sri Lanka & Maldives

- Currently, diesel engines are the primary mode of small-scale electricity generation. But the problems associated with the diesel generation facilities have forced the planners to think about other alternatives like the Microturbines etc. However, while the initial cost of microturbines is higher than that of diesel, higher maintenance cost and short interval between overhauls of diesel engines make the cost of electricity from diesel only slightly lower than that for microturbines

- Microturbines can greatly reduce the environmental impact of NOx, CO, and unburned hydrocarbon (UHC) emissions as compared to the widespread use of diesel generation
- The best approach to introducing microturbines in Maldives and Sri Lanka appears to be through:
  - Combined cooling, heating, and power generation
  - Power generation from biomass-derived gaseous fuel

The demand for electricity in remote areas not connected to the grid can effectively be meet through the distributed generation facilities, such as the microturbines reciprocating engines, micro-hydro, wind, solar photovoltaic, fuel cell, and Stirling Engines. The viability and eventual market share of any technology depend on several factors. The most important of which are cost of generation, environmental benefits, availability (capacity factor), adaptability to combined electric and non-electric applications, and ability to use alternative fuels.

The cost of generation of alternative technologies is illustrated in Figure ES-1. From the cost of generation point of view, micro-hydro is the most economical option to meet the demand of electricity in the areas where such potential exists. However, given the location of hydro resources and availability of water, micro-hydro does not provide an alternative solution throughout the country. In the case of Sri Lanka, micro-hydro potential is located in the central hilly region. Moreover, the potential has already been exploited to the extent possible. The present generation capacity from the micro-hydro resources in Sri Lanka is of the order of 20,000 kW. Maldives does not have any hydro potential. Thus, this technology does not provide an option to meet future power needs for that country.

Photovoltaic is the most expensive technology and cannot generate electricity round the clock, as it is dependent on solar radiation. With government and other subsidies, this energy source is being exploited to the extent of about 12,000 kW in the rural areas of Sri Lanka.

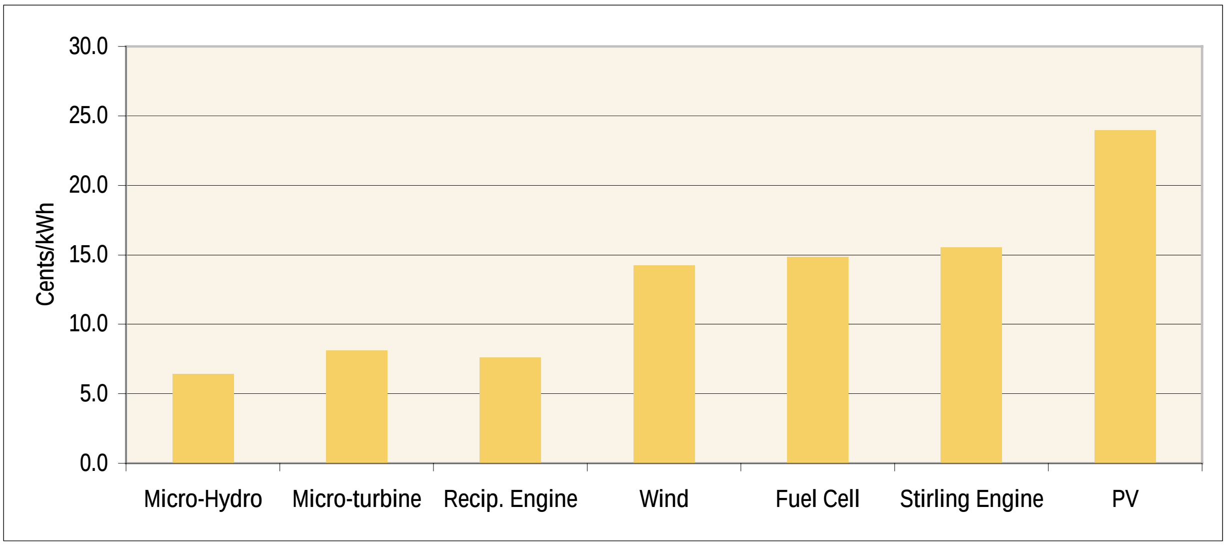


Figure ES-1 Comparative Cost of Generation of Alternative Technologies

The costs of electricity from wind, fuel cell and Stirling engine technologies are high, making them uneconomic at the present stage of development.

This leaves microturbines and reciprocating engines as the two technologies best suited to meet the small-scale electricity generation needs of Maldives and Sri Lanka.

From the environmental perspective, emission of NOx, carbon monoxide, and unburned hydrocarbons are of global concern. Emissions of these pollutants from microturbines are much lower than those from diesel engines by factors ranging from 10 to 100.

- **Based on the findings of the study, microturbines and reciprocating engines offer the best prospects for meeting the electricity needs of rural households and some un-served urban consumers in Maldives and Sri Lanka.**

- **Microturbines offer an environmentally preferred solution over reciprocating engines for supplying small-scale electric power.**

At present more than 3,000 microturbine modules are in operation world wide with a cumulative operating experience of more than one million hours. The major application of this technology is in the filed of combined air conditioning, heating, and electric power generation using conventional fossil fuels as well as various gases produced from biomass such as rice and sugar mill residues. Microturbines are being rapidly introduced for rural electrification in many developing countries, including Thailand, Malaysia, Indonesia, China, Kenya, Nigeria, and Bangladesh. For example, Capstone Microturbines have a subsidiary in Kuala Lumpur and Ingersoll-Rand has a partnership with Tata in India.

Use of biomass for generating electricity is of particular significance to Sri Lanka, Maldives and essentially the entire South Asia region. Two of the primary biomass products that are available in abundance include rice husk and rice straw. Large quantities of low-Btu gas can be produced from these products with the help of biomass gasifiers. Microturbines will become available in the near future that can use such low-Btu gas.

Based on these considerations, it may be concluded that the initial viable applications of microturbines would be for combined heat and power (CHP) and generation of electricity using bio fuels.

Even though there is a significant market potential for microturbines, there are a number of deployment issues including affordability, financing, institutional and policy issues, government regulations, grid connectivity, utility tariffs, future electric utility policies, and market acceptance. These issues are, however, not unique to microturbines but would impact deployment of any type of generating system to varying degrees. In order to facilitate deployment of microturbines to meet growing electricity demand in rural and some urban areas, the governments of Sri Lanka and Maldives need to address these issues.

The purpose of this study is to make an initial assessment of the economic viability of microturbine technology to help meet the electric power needs of rural/remote areas as well as un-served urban areas of developing countries of South Asia. Evaluate the end-use market for this technology initially for Sri Lanka and Maldives.

1.1 Background

The past decade has witnessed considerable growth in electricity consumption in the developing countries of South Asia. Two main forces driving energy demand in these countries have been population growth and economic development. While the demand is rising, electric utilities and governments face serious constraints in expanding electricity generation capacity, fast enough to meet consumer needs. Environmental and social factors also are increasingly important elements that influence the growth of electric power supply in many developing countries. Domestic opposition to establishment of large power generation facilities based on coal, has sometimes impeded growth due to environmental concerns.

Large-scale introduction of combustion turbines can helped ease the environmental situation to some extent. Although combustion turbine technology is mature, its development continues, particularly towards smaller size units. The lowest end of these turbines is referred to as 'microturbines.' The drive towards smaller size is the result of several factors, including utilitie's reluctance to install large units due to the uncertainty in future demand, environmental concerns, and financial constraints. Smaller units offer the flexibility of adding units in stages as demand grows. A further motivation stems from the suitability of smaller units in meeting peak demand, emergency/backup power, and quality power requirements. A third motivation is that small units are ideal for remote areas which often cannot be connected to the grid due to difficulty of terrain, or demand too low to justify grid connectivity on technical and/or commercial grounds.

The problem of poor access to electricity is a global phenomenon. Providing energy solutions to sparsely populated remote areas and un-served urban areas in South Asia has traditionally been a challenge to the governments in the region. The demand in remote areas is low and dispersed, and urban areas often face the difficulty of meeting emergency backup power for industries. Moreover, utilities find it difficult to meet peaking loads in many urban commercial and residential communities.

1.2 Potential Market

A number of alternative solutions exist to meet this challenge. Small-capacity power generation units have been demonstrated as a potential solution. These generating units offer a number of benefits including:

- No long transmission lines, only local distribution
- Low equipment costs and line losses
- Small packaged units—factory assembly and very short installation time
- Availability—available on short lead time
- Load growth, units can be added in stages as demand grows - can alleviate problems created by incorrect load forecasts or transmission and distribution shortfalls

- Quick start-up—can be started on short notice

Small on-site power generation has many applications including:

- Rural and remote power—supply power to users in remote and un-served areas
- Premium power—reduced frequency variations, voltage transients, surges, dips or other disruptions
- Standby power—used in the event of an outage as a back-up to the utility grid
- Peak shaving—used during times when electricity prices are high
- Low-cost energy—use as base-load or primary power that is less expensive to produce locally than it is to purchase from an electric utility
- Combined heat and power (cogeneration)—increases the efficiency of on-site power generation by using waste heat

End-users of on-site generation have different power needs, such as:

- Hospitals need high reliability (back-up power) and power quality (premium power) due to the sensitivity of equipment
- Industrial plants typically have high energy bills, long production hours, and thermal processes, and in certain circumstances would seek on-site generation that could provide low-cost energy and combined heat and power
- Computer data centers require steady, high-quality, uninterrupted power (premium power)

Today a variety of small power generating technologies, developed specifically for these types of application, are commercially available. Microturbines, combustion turbines, reciprocating internal combustion engines, fuel cells, micro-hydro, wind and solar photovoltaic are among such alternative power generating technologies. In view of the problems faced by South Asian countries, the U.S. Agency for International Development (USAID) initiated this study with the objective of finding alternative solutions to address these problems and to evaluate if microturbines can provide an economic source of power. It was decided to conduct the study in two phases:

- Phase-I—Evaluate the technological readiness of microturbines in SARI/Energy countries
- Phase-II—Assess the market potential and economic viability of this technology in meeting the energy requirements described above

Phase-I of the study was completed in September 2002. That study suggests that microturbine technology is commercially viable and ready for deployment to provide electricity to the areas indicated above.

Phase-II is the subject of this current study. The initial focus of the study has been Maldives and Sri Lanka. Later, other SARI/Energy countries may be added subsequently.

This section provides an overview of the approach and method used in conducting the market assessment for microturbines. The sequential steps used for assessment are:

- Assess the economic and environmental viability of microturbines compared to other technologies
- Estimate the market potential of microturbines
- Identify a viable market entry path for microturbines, i.e., a viable initial application strategy

2.1 Economic and Environmental Viability

Small-scale on-site generation can done by a number of generation technologies including microturbines, reciprocating engines, micro-hydro, wind, solar photovoltaic, fuel cell, and Stirling engines. Thus, as a precursor to estimating market potential of microturbines, economic and environmental viability of microturbines compared to other technologies is the first requirement . The viability and eventual market share of any technology depend on several factors, the most important of which are cost of generation, environmental benefits, availability (capacity factor), and adaptability to combined electric and non-electric applications and alternative fuels. These factors are assessed for each of the alternative technologies to determine the economic and environmental viability of microturbines.

The economic and environmental viability of microturbines are assessed in Section 4.

2.2 Estimating Market Potential

One of the most accurate methods of estimating a market is to use a “bottoms up” approach, where market potential is estimated starting from the needs of the smallest unit of a consumer entity. In the case of the electric power market, the smallest unit is an individual human consumer for the residential market and an individual enterprise for the commercial and industrial market. However, it is not economically practical to consider the needs of each individual consumer. A statistical approach is taken, where the needs of groups having similar requirements are estimated. The consumer entities in this approach are ‘households’ for the residential market and ‘groups of enterprises with similar needs’ for the commercial and industrial market.

A basic requirement for assessing market potential for an electricity generating technology is to have adequate information on demography; electricity generating capacity and supply; and the demand/consumption for the various segments and user groups indicated above. A number of organizations and agencies, including governments, banks, census bureaus, and electric utilities generally collect, maintain, and publish this information. But in many countries, it is difficult to collect a full complement of such information for various reasons. Consequently, much of the relevant and necessary information is not available. Developing such information would require in-depth studies of consumer needs. Many surveys would be needed to collect the required information. This would need a much bigger effort and a longer schedule than used here. Therefore, in this study, available published information is used along with the opinions, perceptions and anecdotal information obtained through private communication with country experts.

2.2.1 Defining the Market

The methodology used for estimating market potential consists of estimating the market at three successive hierarchical levels: base, technical, and economic markets. This method is illustrated in Figure 2-1 and discussed in the following paragraphs. Market definition developed by Electric Power Research Institute (Ref. 30) is applied here.

The three levels of markets are defined with the following hypothetical example. Suppose there are 100 houses in a community. Say only 40 of these houses have electricity and do not require new connections. This leaves 60 houses that do not have any electricity. Thus, these 60 houses are potential consumers for electricity, which could be supplied by microturbines. Now let's say only **50%** of these 60 houses finds the cost of electricity supplied by microturbines attractive to them. In the context of this example, the various levels of markets are defined as:

- Base market: All 100 houses of the community (all consumers)
- Technical market: 60 houses (consumers who do not have electricity)
- Economic market: 30 houses (consumers who are potential buyers)

In summary:

The ***base market*** is the total consumer base, i.e., the total number of consumers for a specific product. Which, in this case, is electric power. In other words, the base market in our case consists of all households, and all commercial, institutional, governmental, and industrial facilities that require electric power. It may be pointed out here that a goal of any country is to provide electric power to all the consumers indicated above. Thus, from that perspective, the base market geographically encompasses the entire country.

The ***technical market*** represents the number of consumers (among all consumers of electric power) whose electric power can be technically supplied by microturbines. Thus, a technical market is a part of a base market and represents those consumers who require electric power but currently do not have access to it or are not connected.

The ***economic market*** represents the number of consumers (among all consumers of the technical market) for whom microturbines also meet their economic criteria, which include cost of electricity. Thus, an economic market is a subset of a technical market and represents those consumers who will find the electric power generated by microturbines economically attractive.

2.2.2 Estimating the Market

Estimating the economic market for microturbines is the primary objective of this study. Assessing market penetration, estimating actual number of consumers that are likely to adopt microturbines, and estimating the timing of implementation of this technology is outside the scope of this study.

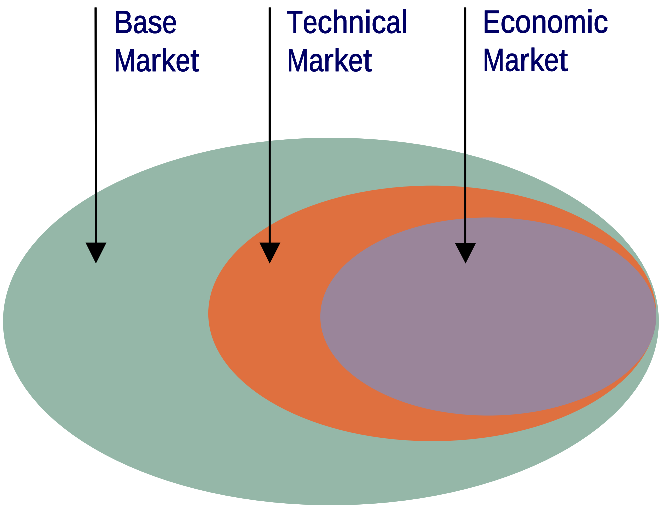


Figure 2-1 Base, Technical, and Economic Markets Definition

Estimating market potential is a three-step process.

- ***Step 1: Segmenting and Estimating Base Market:*** Estimating the market for a technology begins with identifying the various segments of the base market, i.e., identifying the various groups and total number of consumers in each group who are likely to have a similar requirement for electric power. Thus, in this step, the total number of consumers in each group is estimated. The totality of these consumers constitutes the base market.
- ***Step 2: Estimating Technical Market:*** A technical market, i.e., the number of consumers who require electric power but currently do not have access to it, is estimated by using available published information along with the opinions, perceptions, and anecdotal information obtained through private communication with country experts.
- ***Step 3: Estimating Economic Market:*** An economic market is that part of a technical market which represents those consumers who will find the electric power generated by microturbines economically attractive. For example, if cost of electricity is the consumer's economic criterion, only those consumers where microturbines represents the least-cost option in meeting their needs would constitute the economic market.

Estimation of market potential for microturbines in Sri Lanka and Maldives are discussed in Sections 5 and 6, respectively.

2.3 Initial Applications of Microturbines

A pathway to introduce microturbines is identified by assessing potential uses of the technology which can be applied in the near term and where the technology offers unique advantages over other technologies Viability of an initial application of microturbines is assessed in Section 7.

3.1 Background

South Asia is an important region to world energy markets because it contains 1.3 billion people and is experiencing rapid energy demand growth. As a result, much of the region is grappling with energy shortfalls, often in the form of frequent, costly, and widespread electricity outages. Given this situation, and in particular its potential economic and political ramifications, improving the supply of energy in general, and electricity in particular, is a major concern among regional governments.

Both Maldives and Sri Lanka have experienced shortages in electricity supply in recent years. Neither of these countries has an indigenous source of fossil energy and, therefore, rely on imported fuel to meet their growing need for electricity. Sri Lanka is endowed with some source of hydroelectric power, which, combined with imported fossil fuel-fired generation, enables Sri Lanka to meet a major portion of its growing demand for electricity. Maldives depends entirely on imported fossil fuel to supply its growing electricity demand.

Worldwide demand for small on-site generation has grown substantially in the past decade. Prime-movers providing on-site electricity or shaft power are increasingly being requested by end-users, utilities and independent power producers (IPP), shifting away from a large central power model. Markets for small power units in general, and for microturbines in particular, encompass many different sectors. These include rural, urban, and sub-urban areas.

3.2 Rural Areas

For the purpose of this study, rural areas are defined as those regions that have no access to electricity as they are far off from electricity grids or where electricity supply is inadequate and is of poor quality. Some of these regions depend almost entirely on biomass fuel such as fuel wood augmented by a small amount of liquid fossil fuel for privately owned diesel power generators and a small amount of gaseous fuel for cooking. Demand for power is low and load centers are dispersed. Because of these conditions, in most cases it is not cost-effective to build electrical transmission and distribution lines. Many countries are aggressively pursuing rural electrification primarily by installing small and dispersed generating units for individual users or small groups of users in communities.

In the island nation of Maldives, the sparsely populated small islands are basically rural in nature although all the inhabited islands have electrical generating units and all households have access to electricity. But the supply of electrical power is very poor in terms of the number of households actually electrified, numbers of hours of supply in a day, and installed capacity.

The primary demand for power in rural areas is for residential (household) consumption. However, as electrification of the residential segment continues to grow, agricultural (irrigation), commercial, and small-scale industries continue to develop, and their need for power contributes to the overall demand for electricity. Depending on the size of a locality, the demand for power is generally in the range of hundreds of kilowatts (kW). Since a large number of localities fall in this category, aggregate demand for power potentially is quite high. Thus the potential market size, in terms of total kW or MW capacity and in terms of the number of small units required to supply this load, would be significant.

3.3 Urban Areas

In contrast to rural areas, urban areas have full access to electricity although a small number of consumers may not be electrified. In addition, the electricity consumption level is higher due to the concentration of commercial and industrial activities. A major concern in urban areas is for backup/emergency power supply. In many countries, urban communities witness low quality power supplies due to power cuts during hours of peak demand. Thus, the challenge in urban areas is primarily to supply backup/emergency power on a cost-effective basis.

The consumers in urban areas that would benefit most from small generating units are households, commercial enterprises, and small-scale industries for their emergency and back-up power requirements. Commercial and small-scale industrial enterprises also could benefit from combined heating and power (CHP).

Small-scale Industrial: Many small-scale industries such as food processing, telecommunication, and pharmaceuticals have very low tolerance levels for power interruption. They suffer from loss of productivity, high labor cost, and waste of processed materials due to loss of power. These industries often require standby/emergency power of high quality to minimize their losses. Many of these industries also could meet their heating and cooling needs by utilizing waste heat from on-site small generating units. Shaving peak power requirement is another potential application for on-site generation for these industries.

Commercial: Hospitals, office buildings, and shopping malls are the primary commercial facilities that could benefit from on-site generation. Hospitals are particularly vulnerable to power interruptions as quality of power is essential for hospital operation. In general, all facilities included in this segment could benefit from standby, emergency, and combined heat and power application of small on-site generating units.

Residential: Even in the residential segments, consumer expectations have risen high. They need to have an uninterrupted supply to operate their lifts, pumping water, air conditioning and to operate household appliances.

3.4 Unit Size

Available unit sizes of small power generating technologies vary considerably, from less than 5 kW to about 500 kW. Most industrial applications require larger units while commercial and residential applications gravitate towards smaller units. Large (500 kW and larger) generating units are suitable for urban areas. However, power for emergency/back-up, un-served commercial, peaking, and remote areas (agricultural and residential) generally calls for small size units. These units can be isolated from the electric grid, thereby reducing or eliminating the cost of building expensive distribution networks.

Residential power demands of individual local communities in rural areas tend to be rather small, in the range of hundreds of kW for each community. Since there are large numbers of communities, collective demand would be significant, totaling to hundreds or even thousands of MW for the South Asia region.

Microturbine installations are configured to provide the highest availability and reliability obtainable at a specific site. Generally, several modules are grouped together to configure a generating unit. The currently available module sizes range from 30 to 100 kW. A 250 kW module will be available around 2004. This module would benefit from economy of scale and would be more efficient compared to the lower capacity modules.

In this section, the economic and environmental viability of microturbines are assessed compared to alternative technologies. A detailed exposition of technological viability of microturbines is given in an earlier report titled "Evaluation Report - Technological Readiness of Microturbines" (Ref. 7).

4.1 Comparative Attributes of Alternative Technologies

A large number of technologies are available to fill the niche for small on-site and off-grid power generating units. These include microturbine, internal combustion or reciprocating engine, Stirling engine, fuel cell, wind, solar photovoltaic, and micro-hydro. The relative attributes (technical and commercialization features) of each of these technologies are shown in Table 4-1. These attributes vary widely from one technology to the other, and even within a technology, due to variations in specific applications. It may be noticed from the table that all of the technologies are capable of covering a wide range of generation capacity including the desired range in the present study, viz., 30 kW to 500 kW. This range is achievable sometimes by multiplexing a number of generating units.

Table 4-1 Comparative Attributes of Alternative Small Power Generation Technologies

	Microturbine Recuperated	Reciprocating Engine	Fuel Cell	Stirling Engine	Wind	Solar PV	Micro-Hydro
Commercial Availability	Current	Current	Current	Early Production	Current	Current	Current
Unit Size Range	30 kW to 250 kW	5 kW to multi-MW	30 kW to multi-MW	30 kW to 100 kW	5 kW to Multi-MW	5 kW to Multi-MW	3 to 35 kW
Fuel Capability	Nat. Gas, Diesel, Biogas, Low Btu Landfill Gas, etc.	Nat. Gas, Diesel, Biogas, Low Btu Landfill Gas, etc.	Natural Gas, Hydrogen	Nat. Gas Primary, Broad Flexibility	-	-	-
Electrical Efficiency	~ 25% to 32%	~ 28% to 35%	~ 25% to 45%	~ 20% to 30%	-	-	-
Heat Recovery Potential	60% to 85% effcy. Steam Gen. & Water Heating	70% to 85% effcy. Water Heating	85% to 95% effcy Steam Gen. & Water Htng.	25 to 55% effcy. Water Heating	-	-	-
Expected Avg. Life Between Overhauls	~ 80,000 Hrs	~ 20,000 Hrs for small engines	~ 40,000 Hrs	~ 60,000 Hrs	Low Maint., Long Life	Low Maint., Long Life	Low Maint., Long Life
Large Vol. Cost	900 to 1,200 $/kW	250 to 500 $/kW	1,600 to 3,000 $/kW	2,000 to 3,000 $/kW	2500-3500 $/kW	3,500 $/kW	1,500 $/kW

Source: Refs. 8, 9, 10, 26, 29

4.2 Comparative Economics of Alternative Technologies

Assessing the economics of alternative technologies is more complex than simply comparing the cost of the basic equipment. As there are many variations in attributes among the alternatives so are there many factors that could affect their relative economics. One such factor is the ability of a technology for cogeneration. As an example, a microturbine is capable of generating power and steam, while a reciprocating engine is capable of generating power and hot water. Exhaust temperature from a reciprocating engine is not adequate for generation of steam. For wind and solar photovoltaic (PV) systems, variations in wind speed, and solar insolation, respectively, affect the economics. Similarly, the amount of rainfall affects the economics of micro-hydro systems. Infrastructure support requirements, such as fuel supply, electrical output synchronization, etc., could vary widely among the alternatives.

Additionally, suppliers tend to give large discounts on volume purchase of new technologies; and governments often give incentives for use of renewable fuels such as biogas, the use of which is more suitable to microturbines than to reciprocating engines. Low interest loans are available from lending agencies like the Asian Development Bank and World Bank for applications with better environmental features. All of these attributes need to be combined to evaluate the relative economics of alternative technologies. The comparative assessment in this section is based on conventional fuels such as natural gas or diesel fuel.

A more accurate assessment of the relative competitiveness of these technologies would require at least some preliminary designs of generating plants using different technologies. In the absence of such designs, the assessment presented here is only for comparative purposes, and the results are only indicative of the trend in cost differentials. However, this trend is not expected to change significantly with a more detailed estimate. A simplified economic analysis is performed to estimate the trend. The comparative economic assessment is presented in Table 4-2 and Figure 4-1.

Table 4-2 Comparative Economics of Alternative Technologies For 250 kW Systems

	Micro-Hydro	Micro-turbine	Recip. Engine	Wind	Fuel Cell	Stirling Engine	PV
Plant efficiency/ factor	40%	32%	30%	30%	25%	20%	20%
Annual energy gen, MWh	876	1,424	1,314	657	1,314	1,314	548
Annual Fuel consumption, 10^6 MJ	3.15	16.01	15.77	2.37	18.92	23.65	1.97
Installed cost, $/kW	1,500	1,100	450	2,500	3,000	3,000	3,500
Total Installed Cost, $K	375.0	275.0	112.5	625.0	750.0	750.0	875.0
Annual fixed charge, $K	56.3	41.3	16.9	93.8	112.5	112.5	131.3
Annual fuel cost, $K	0.0	53.1	52.3	0.0	62.7	78.4	0.0
Annual O&M cost, $K	0.0	21.4	32.9	0.0	19.7	13.1	0.0
Total Annual Operating Cost, $K	56.3	115.7	102.0	93.8	194.9	204.0	131.3
Cost of Electricity, Cents/kWh	6.4	8.1	7.8	14.3	14.8	15.5	24.0

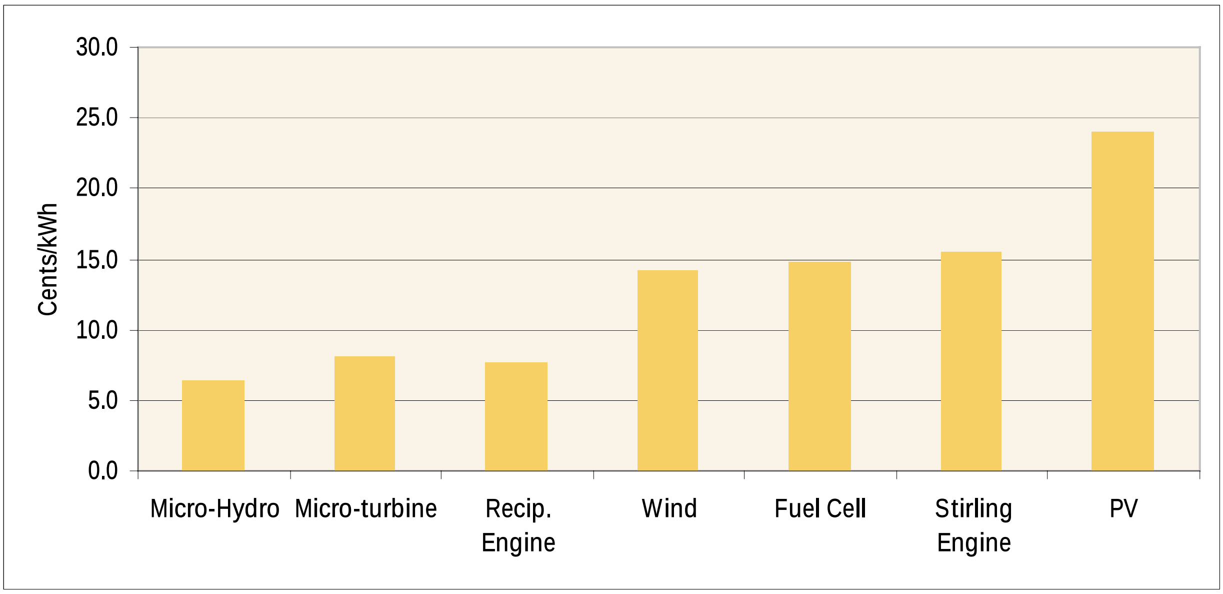


Figure 4-1 Comparative Cost of Generation of Alternative Technologies

A review of the data in Table 4-2 reveals that micro-hydro is the most economically attractive generation option with respect to the cost of electricity generation. However, the total potential of micro-hydro in Sri Lanka is only about 20,000 kW and this potential is concentrated in the central hilly areas of the country. An accurate estimate of this potential is not available, but based on available information, could be on the order of several tens of MW.

Microturbines and reciprocating engines offer the next best generation option in terms of cost of generation. The cost of generation from microturbines is somewhat higher than for reciprocating engines, but they should be considered as the same, at about 8 cents/kWh, since the difference falls within the error margin of the estimate. Between microturbines and reciprocating engines, the latter option has an advantage of lower capital investment. However, noisy operation and frequent maintenance requirements are some of the disadvantages.

Cost of electricity from wind, fuel cell, and Stirling engines are on the same order of magnitude, around 15 cents/kWh, and the differences also fall within the error margin of the estimate. Small-scale non-grid application of wind has a high investment requirement per kilowatt of power installed. Unless subsidized, the investment cost would be about $3,500 to $4,000 per kW. In addition, wind's annual capacity factor or availability is low due to a high variability of wind velocity. CEB's 3 MW wind plant in the south achieved a plant factor of **12.8 %** in the year 2000. However, for the purpose of the current study, a conservative capacity factor of **30 %** is used. At this capacity factor, wind turbines offer the third lowest cost of electricity. Fuel cell and Stirling Engine systems are economically much less attractive than either microturbines or reciprocating engines or wind turbines due to the former two systems' high investment, fuel, and O&M costs.

The photovoltaic (PV) system is the least attractive alternative because of its low capacity factor, high investment cost and high cost of produced power. The best capacity factor that can be expected is around **20 %.**

In developing the economics of wind and photovoltaic systems presented here, the capital cost data provided by Energy Forum, based in Colombo, was used. The capital costs used here are

$2,500/kW and $3,500/kW for wind system and photovoltaic system, respectively. This results in electricity costs of 14 cents/kWh and 24 cents/kWh, for wind and photovoltaic systems, respectively (Table 4-2). It is interesting to note here that a study by Asian Development Bank for Maldives (Ref. 21) found that costs of electricity from these two sources of power would be in excess of $1.00 per kWh.

The comparative economic analysis presented above indicates that micro-hydro is the economically most attractive small capacity generating option. However, its applicability is limited due to low total generating capacity potential; unsuitability for nationwide deployment; non availability around the year; and potential requirement for relatively long distribution lines from the generating source. Thus, the analysis indicates that from the cost of electricity point of view, microturbines and reciprocating engines are the two alternative technologies that offer the economically best small-scale on-site generation options in Maldives and Sri Lanka.

4.3 Environmental Viability of Microturbines

In the small-scale on-site generation technology market, reciprocating engines appear to be the primary alternative to microturbines at present. However, globally, there is one compelling parameter that favors the choice of microturbines for generation technology. Concerns for emission of pollutants is shaping the power generation market in the western world. Emissions criteria are so restrictive in many countries that it is almost impossible to license a baseload diesel generation plant. Small diesel engines (< 500 kWe) will not be able to meet stricter emission criteria in the near future without further expensive development. Emission of nitrogen oxides (NOx), a major contributor to acid rain and smog formation in urban areas, is the largest concern. Microturbines have the advantage over reciprocating engines, where the NOx emissions from the former is 100 times lower than from the latter. The emission differences are shown in Table 4-3.

Table 4-3 Environmental Impacts of Microturbines and Reciprocating Engines

		Microturbines	Reciprocating Engines
	Installation Size	200 kW	150 kW
	Total Installed Cost per kW	$1,100	$450
NOx Emission*	ppmv @15% O_2	< 9	1,000
CO Emission*	ppmv @15% O_2	10-40	100-3,000
UHC Emission*	ppmv @15% O_2	5-10	150-450

* Without exhaust treatment * Source – IEA, Power Engineering, and EPRI

A brief overview of Sri Lanka's present electricity generation and demographic profile is given in the following subsections.

5.1 Electricity Generation

Sri Lanka has experienced significant growth in electricity consumption in recent years. As of 2001, the country's total generating capacity was 1,999 MW with the addition of 161 MW. Sri Lanka's electricity generating capacity is dominated by hydro (1,161 MW). The balance is thermal (835 MW) and a small amount of wind-generated power (3 MW). These include both publicly and privately (independently) owned power plants (IPPs).

Ceylon Electricity Board (CEB), the state-owned electric utility, is the primary supplier of electricity in Sri Lanka. It supplies about **76%** of total electricity generated in the country. In 2001, total generation of electricity was 6,520 GWh of which CEB's share was 4,945 GWh, not including a small amount of self-generation. While CEB is the sole state-owned electricity generating entity, Lanka Electric Company (LECO) is the state-owned distribution company, which is responsible for distributing electricity to certain parts of the country.

Sri Lanka has a strong rural electrification program using renewable energy sources including micro-hydro, solar, and wind. Energy Forum[1], a state-owned agency based in Colombo, is actively pursuing the program. With subsidies from the Sri Lanka Government and World Bank, an aggressive solar photovoltaic program is under way. There are approximately 300,000 rural households that are targeted for electrifying with solar photovoltaic panels of 40 W per panel. This represents a total potential of about 12,000 kW. 25,000 households have already been electrified with a total capacity of about 1,000 kW. A World Bank loan is in progress to electrify an additional 85,000 households.

There is a strong micro-hydro program in place for electrifying 1,000 villages with an average of 40 households per village. According to Energy Forum, this represents a total potential capacity of 15,000 to 20,000 kW.

For wind power, the potential for off-grid power has not been clearly identified. With respect to on-grid wind power, CEB has estimated a potential of more than 50,000 kW.

Lately, Sri Lanka has been experiencing power shortages from time to time mainly because of a shortage of baseload power generating capacity. These power shortages emphasize the need to have alternative power supplies, particularly for meeting the needs of industrial and commercial customers where the effects of such shortages are likely to be substantial in economic terms. Studies have estimated that the costs of un-served energy for the Sri Lankan system range from 66 cents/kWh to more than one U.S. dollar per kWh.[2] Most of the medium and large-scale industries have their own on-site generators. But many of these generators are inefficient. In addition, noise pollution is a significant factor, particularly when the industries utilizing emergency/backup generators are located in the vicinity of urban and residential areas.

[1] Private Communication, Mr. Asoka Abeyagunawardana, Program Coordinator, Energy Forum, Colombo, 10 February 2003.

[2] Assessment of Economic Impact of Poor Power Quality on Industry, Nexant, October 2002

CEB has recently estimated that the country needs to boost electricity generation by about 150 MW per year at least through 2016. This is based on the **7 to 8 %** growth rate in consumption that Sri Lanka has experienced over the last several years. This addition in capacity would be primarily thermal, as the country's economically recoverable hydro potential has already been developed. However, CEB has planned for the addition of several hydro plants, and identified a number of small, mini/micro hydro plants for development. The cost of installation and cost of electricity from these latter plants are expected to be very high.

5.2 Population Distribution

The current population of Sri Lanka is about 19.4 million. About **61%** of the population has access to electricity from the national electricity grid. Data published by the Central Bank of Sri Lanka indicates that about **20%** of the population live in urban and estate areas and **80%** lives in rural areas. Based on the published and unpublished (obtained through private communication) data from CEB, and other documents obtained from Central Bank of Sri Lanka, as of 2001, Sri Lanka's electricity consumers can be grouped as shown in Table 5-1.

Table 5-1 Sri Lanka's Population Distribution

Consumer Segment/Group	Number of Units
Total number of rural residential households	3,996,000
Total number of urban & estate residential households	928,000
Total number of commercial consumers	274,515
Total number of small industrial consumers	25,345
Total number of medium industrial consumers	3,450
Total number of large industrial consumers	120

Nexant recently conducted a study (Assessment of Economic Impact of Poor Power Quality on Industry, Nexant, October 2002) on the cost of poor quality of electrical power for a combination of medium and large industrial consumers. A total of about 3,000 consumers were included in the study and it was estimated that about **92%** have some form of emergency/backup generation capability to help meet their demand. Many of these consumers would benefit from additional on-site standby generation capacity.

5.3 Estimation of Microturbine Market in Sri Lanka

The methodology outlined in Section 2 is applied to estimate the microturbine market in Sri Lanka. The first step is to identify the segments and consumer groups within the base market and estimate the number of consumers in the segments/groups. Based on the data available, consumers in Sri Lanka are divided into three segments: rural, estate, and urban. Since the estate segment is relatively small, this segment is combined with the urban segment, and for simplicity the combined segment is referred to as urban. The rural segment consists of a homogeneous group of residential (household) consumers. The urban segment is further divided into three groups. Thus the segments of Sri Lankan electricity consumers are as follows:

Consumer Segment/Group	Type of Power Needs
Group 1: Rural residential (household)	Basic power
Group 2: Urban residential (household)	Backup power
Group 3: Urban commercial & small industrial	Emergency/backup power and combined heat and power
Group 4: Urban industrial (medium & large)	Emergency/backup power and combined heat and power
Group 5: Urban industrial	Bio fuel and other fuel use

The Group 3 segment (urban commercial & small industrial) has a relatively large consumer base – on the order of 300,000. Annual electricity consumption of this group is high and is about **60 %** of that of Group 4 (urban industrial - medium & large). However, due to the limited resources of the present study and the lack of available data, the extent of their needs for the indicated type of power could not be estimated accurately. For the purpose of this study, a rough order-of-magnitude size is assumed. It would require a detailed survey in order to estimate the number of consumers and their power needs for these two groups.

5.3.1 Step 1: Market Segments and Base Market in Sri Lanka

As discussed in Section 5.2, the number of consumers in each segment and group is shown below:

Consumer Segment/Group	Number of Consumers
Group 1: Total number of rural households	3,996,000
Group 2: Total number of urban households	928,000
Group 3: Total urban commercial & small industrial consumers	300,000
Group 4: Total urban industrial consumers (medium and large	3,570

5.3.2 Step 2: Technical Market in Sri Lanka

The technical eligibility criteria are as follows:

Consumer Segment/Group	Technical Eligibility Criteria	
Group 1: Rural Residential	Percentage of rural households that do not have access to electricity or that are not electrified	47.4%
Group 2: Urban Residential	Percentage of urban households that can use backup power	80%
Group 3: Urban Commercial & Small Industrial	Percentage of consumers that need emergency-backup power and combined heat and power	50%
Group: 4 Urban Industrial - Medium and Large	Percentage of consumers that need emergency-backup power and combined heat and power	50%

In the absence of specific data, and relying on discussions with sector participants, the following assumptions are made for Groups 2, 3, and 4:

- Group 2: Majority, about **80%,** of urban population lives in apartment buildings, which currently do not have backup generators. Thus all these households can use backup power.
- Groups 3 and 4: The Nexant study, cited earlier, estimated that **92%** of these consumers have some form of emergency/backup generation capability to help meet their demand. However, many of these consumers would benefit from additional on-site standby generation capacity. Thus it is assumed that approximately **50%** of these consumers meet the technical eligibility criteria.

5.3.3 Step 3: Economic Market in Sri Lanka

The economic eligibility criteria are as follows:

Consumer Segment/Group	Economic Eligibility Criteria*	
Group 1: Rural Residential	Percentage of technically eligible consumers who would pay the cost of power from microturbines compared to other forms of electricity generation	100%
Group 2: Urban Residential	Percentage of technically eligible consumers who would pay the cost of backup power from microturbines compared to other forms of electricity generation	100%
Group 3: Urban Commercial & Small Industrial	Percentage of technically eligible consumers whose backup/emergency generators are due for replacement or upgrade and would pay the cost of backup power from microturbines compared to other forms of electricity generation	50%
Group: 4 Urban Industrial - Medium and Large	Percentage of technically eligible consumers whose backup/emergency generators are due for replacement or upgrade and would pay the cost of backup power from microturbines compared to other forms of electricity generation	50%

* The Percentage values of the above economic criteria are assumed based on the following assumptions and considerations:

- Groups 1 and 2: The combined economic and environmental benefits for these customers from microturbines are superior to those of other forms of electricity generation. Initial government subsidy, manufacturer discount, and enforcement of strict environmental criteria are assumed. In many parts of the world, a government subsidy or other policy to promote small-scale generation is becoming a standard practice to help meet environmental requirements . From these considerations, it is assumed that all consumers meet the economic eligibility criteria.

- Groups 3 and 4: About **50%** of the existing generator sets are due for replacement due to aging. This is an indicative number, which needs to be substantiated by detailed surveys.

Thus the economic market in Sri Lanka is estimated as follows:

Economic Market = Base Market x Technical Eligibility Criteria x Economic Eligibility Criteria

Consumer Segment/Group	Economic Market (# of Consumers)
Group 1: Rural Residential	3,996,000 x 47.4% x 100% = 1,894,000
Group 2: Urban Residential	928,000 x 80% x 100% = 742,400
Group 3: Urban Commercial & Small Industrial	300,000 x 50% x 50% = 75,000
Group: 4 Urban Industrial - Medium and Large	3,570 x 50% x 50% = 892

The economic market estimated above is in terms of number of customers. The economic market in terms of kW capacity is estimated and is shown in the following table:

Consumer Segment/Group	Economic Market, kW
Group 1: Rural Residential	Ceylon Electricity Board estimates that peak capacity demand in the rural areas varies from 0.20 kW to 0.25 kW per household depending on the size of the household. Thus it is assumed that on average, 0.225 kW would be the demand per household. Thus, economic market for Group 1 = 1,894,000 x 0.225 = 426,150 kW.
Group 2: Urban Residential	Using CEB's average capacity demand of 0.25 kW per urban household, peak capacity demand of Group 2 = 742,400 x 0.25 = 185,600 kW.In the absence of available data, it is assumed that 20 % of the peak demand is used as backup capacity. Thus, economic market size for Group 2 = 185,600 x 0.20 = 37,120 kW.
Group 3: Urban Commercial & Small Industrial Group: 4 Urban Industrial - Medium and Large	Emergency/backup power needs of these consumers could not be developed due to the resource limitation of the present study. As indicated earlier, a Nexant study estimated that 92% of these two groups of consumers has independent generator sets. From imports records, it is estimated that total capacity of these sets is 566,000 kW. This is considered to be the base market for these two groups. Using technical and economic eligibility criterion indicated earlier, the economic market for Groups 3 and 4 = 566,000 x 0.5 x 0.5 = 141,500 kW.

Therefore, total estimated economic market size for microturbines in Sri Lanka is presented in Table 5-2.

Table 5-2 Estimated Economic Market Size for Microturbines in Sri Lanka

Consumer Segment/Group	Economic Market, kW
Group 1: Rural Residential	426,150 kW
Group 2: Urban Residential	37,120 kW
Groups 3 and 4: Urban Commercial and Small, medium, and Large Industrial	141,500 kW
Subtotal	604,770 kW
As discussed earlier in Section IV.1.0, the estimated demand that may be satisfied by micro-hydro, solar, and wind is approximately	34,770 kW
Total Economic Market for microturbine in Sri Lanka	570,000 kW

A brief overview of Maldives' present electricity generation is given in the following paragraphs.

6.1 Electricity Generation and Population Distribution

Maldives' current total installed generating capacity is about 105 MW. Of this, about 51 MW is privately owned and is located primarily at the 83 resort islands. The country is completely reliant on imported fossil fuels; and diesel-burning generating units provide almost all generation.

Due to the unique geographical nature of the archipelago, almost all of Maldives' electrical generation capacities are distributed on-site on the islands. There is no inter-island electrical transmission line.

State Electric Company (STELCO) is the primary supplier of electricity in the country. The company supplies about **60%** of the country's electrical needs. Of the total of about 200 inhabited islands, STELCO currently supplies electricity to the Capital City of Male and 23 large islands, here referred to as 'STELCO Islands' for convenience. These islands have a relatively large population compared to the rest of the islands. The rest of the islands are referred to as 'outer islands'. In addition to the large islands, STELCO serves a number of small islands which are used for industrial purposes such as storage of fuel oil, engine spare parts, etc.

Maldives enjoys one of the highest per-capita consumption rates of electricity among South Asian countries, approximately 400 kWh per year, which is essentially due to high consumption in the City of Male and in the large STELCO islands. The capital city of Male enjoys the highest per-capita consumption, approximately 1,200 kWh per year.

The small outer islands have quite low electricity consumption. The Asian Development Bank (ADB) has conducted detailed studies of the electrical supply conditions in the outer islands. Although access to electricity has improved, electric supply systems in the outer islands are generally inadequate. Hours of operation are often restricted, quality is usually poor, and the systems are inefficient. Poor quality of electricity supply also suppresses demand, as consumers are often reluctant to invest in electrical appliances. Currently, many of the outer island households have access to electricity only for 5 to 12 hours a day. The efficiency of the power supply systems in most of the outer islands is low and system losses are high. The unreliable electricity supply in the outer islands also inhibits economic development.

Electricity tariffs in the outer islands are very high. With private companies supplying electricity, the average tariffs are usually in the range of 27 U.S. cents/kWh to 31 U.S. cents/kWh, and can be as high as 78 U.S. cents/kWh in some islands.

Maldives has a population of about 270,000. In light of the geographic structure of the country, the population is divided into the groups as shown in Table 6-1.

Table 6-1 Maldives' Population Distribution and Installed Generating Capacity in 2001

Region	Population	Households	Total Installed Capacity kW	Installed Capacity kW/Household
Male City	74,000	13,000	19,000	1.46
STELCO Islands	94,000	18,000	25,000	1.39
Outer islands	106,000	20,000	10,000	0.05
Resorts	-	-	51,000	-
Total	270,000	51,000	105,000	-

Source: Refs. 3, 4, 5, 6, 22, 23, 24

It may be noticed that Male City has the highest installed capacity per household, whereas the outer islands have the lowest.

6.2 Estimation of Microturbine Market in Maldives

As in the case of Sri Lanka, the methodology outlined in Section 2 is applied to estimate the potential microturbine market in Maldives. The first step is to estimate the number of consumers in various segments and groups. Based on the data available, consumers in Maldives are divided into three segments: small outer islands, City of Male, large islands served by State Electricity Company (STELCO), and resort islands. The small outer islands segment and the large STELCO islands segment each consists of a homogeneous group of residential consumers (households). The City of Male consists of two groups: residential (household) and industrial & commercial. The industrial islands have only a small number of industrial consumers. The resort islands segment consists of a homogeneous group of hotel and resort consumers. Thus the segmentation of Maldives consumers is as follows:

- Group 1: Small Outer Islands - Residential (household)
- Group 2: Large STELCO Islands - Residential (household) & City of Male
- Group 3: Industrial Islands - Industrial & commercial & City of Male
- Group 4: Resort Islands - Hotels and resorts

Consumers in each of these groups have a need for adequate and good quality electrical power.

6.2.1 Step 1: Market Segment and Base Market in Maldives

Number of consumers (households) in the various groups are as shown below:

Consumer Segment/Group	Number of Consumers
Group 1: Small Outer Islands - Residential (household)	20,000
Group 2: Large STELCO Islands - Residential (household & City of Male	31,000
Group 3: Industrial Islands - Industrial & commercial	6,000
Group 4: Resort Islands - Hotels and resorts	83

6.2.2 Step 2: Technical Market in Maldives

The technical eligibility criteria are as follows:

Consumer Segment/Group	Technical Eligibility Criteria	
Group 1 Outer Islands	Percentage of households that do not receive adequate and good quality electric power or that are not electrified	100%
Group 2 STELCO Islands & City of Male Households	Percentage of households that do not receive adequate and good quality electricity or that are not electrified	Very Small
Group 3 STELCO Islands & City of Male Industrial & Commercial	Percentage of consumers that do not receive adequate good quality electricity or that are not electrified	Very Small
Group 4 Resort Islands	Percentage of consumers that do not receive adequate good quality electricity or that are not electrified	Very Small

Discussions with the various stakeholders indicate that of the four market groups above, almost all consumers in Groups 2, 3, and 4 are receiving adequate quality electrical power although a low potential exists within the Groups 3 and 4 for combined heating and power (CHP). However, a detailed survey would be required to estimate this potential, which is beyond the scope of this study. Thus in this initial assessment of the microturbine market, estimation of CHP potential is excluded. However, economic benefits of using microturbines for combined heating and power are discussed in Section 7.

6.2.3 Step 3: Economic Market Size in Maldives

The economic eligibility criterion is:

Name of Group	Economic Eligibility Criteria	
Group 1 Small Outer Islands – Residential (Household)	Percentage of technically eligible consumers who would pay the cost of power from microturbines compared to other forms of electricity generation	100%

As in the case of Sri Lanka, the above value of the above economic criteria is assumed based on the following considerations: Combined economic and environmental benefits of microturbines are superior to those of other forms of electricity generation. Also, initial government subsidy, manufacturer discount, and strict environmental criteria are assumed. Thus all consumers meet the economic eligibility criteria.

Thus the economic market in Maldives is estimated as follows:

Economic Market = Base Market x Technical Eligibility Criteria x Economic Eligibility Criteria

Consumer Segment/Group	Economic Market (# of Consumers)
Group 1: Small Outer Islands -Residential	20,000 x 100% x 100% = 20,000

The economic market estimated above is in terms of number of customers. The economic market in terms of kW capacity is estimated as follows:

From the data obtained from STELCO, it is estimated that the installed electrical generating capacities in the City of Male and the large STELCO islands are approximately 1.46 and 1.39 kW per household, whereas the current installed electrical generating capacity in the small outer islands is, on an average, approximately 0.50 kW per household. This disparity is primarily due to improper planning and reluctance to supply adequate good quality power by the independent power providers in these islands. The Asian Development Bank has determined that the consumers in these islands are willing to pay a higher price for electricity. Considering the above, it is assumed that an average installed capacity of 1.0 kW per household would be appropriate for these islands.

Thus, economic market size for Group 1 = 20,000 x 1.0 = 20,000 kW

Again, from the Ministry of Planning and National Development data, the small outer islands already have a total installed capacity of about 10,000 kW. Thus the actual economic market for microturbine in Maldives is estimated at 10,000 kW.

With the technologies evolving rapidly, it is difficult to predict which type of generation will be most frequently adopted for a specific application. Although several technologies may be appropriate for a specific application, a number of factors need to be considered in selecting the optimal technology. These factors include the initial cost, electrical efficiency, fuel flexibility, application diversity such as combined heat and power, and maintenance requirements for both routine and longer-term overhauls, as well as the cost and availability of those services.

Microturbines offer several distinct advantages over reciprocating engines for small-scale off-grid applications. With just one moving part, they are much easier and cost less to operate and maintain. They have longer, and unlike reciprocating engines, require neither liquid lubricants nor coolants, thus simplifying operations and maintenance. They also produce much less nitrogen oxide (NOx) emissions than reciprocating engines.

At present more than 3,000 microturbine modules are in operation worldwide with a cumulative operating experience of more than one million hours. The majority of these applications are for combined electric and non-electric energy generation using conventional fossil fuels as well as biogas and biomass-derived gaseous fuels. (Biogas, such as landfill gas, and biomass-derived gaseous fuels, such as producer gas from rice husk, are also referred to as bio fuels.)

7.1 Microturbines for Combined Heat and Power

7.1.1 Integrated Use of Microturbines and Absorption Chillers for Cooling Applications

One key advantage that a microturbine has over a reciprocating engine is its ability to support combined air conditioning, heating, and electric power generation, commonly known as combined heat and power (CHP) generation. High temperature exhaust from microturbine can be used in an absorption chiller to generate chilled air for air conditioning. Currently, this is the major application of microturbines. This integrated system is an effective way to use turbine waste heat. It also allows the chiller to cool the turbine inlet air to increase the generation capacity and to reduce the power demand of air conditioning when electricity prices surge during hot days. A combined system can be packaged for lower cost, and can be distributed by the existing heating, ventilation and air conditioning (HVAC) sales and service infrastructure. An analysis (Ref. EPRI, Nov. 2000) shows this integrated system is cost effective for users who pay high electricity costs, either through time of use rates or demand charges, during hot days. A case study based on a large commercial building with real time pricing shows that the payback of the integrated system could be less than 4 years. The payback would be shorter when peak prices are higher than assumed in the example.

7.1.2 Integrated Generation of Power and Steam

Many commercial and industrial facilities have a simultaneous need for electric power and steam. The high exhaust temperature from a microturbine allows for the generation of steam, which is used for commercial and industrial applications. This cannot be done with a reciprocating engine. This application makes the overall system efficiency approach **85%** compared to **29 to 32%** for generation of electricity only. These two key features distinguish microturbines from reciprocating engines.

7.2 Microturbines with Low-BTU Biomass Fuels

The fuel flexibility of microturbines is another technical attribute of this technology that could affect its applicability to markets in Madlives and Sri Lanka. In addition to using standard fuel oil or natural gas, a microturbine is adaptable to other fuels such as producer gas from biomass (wood chips, straw, bagasse, rice hull, sugarcane juice, etc.) and biogas from landfill, animal waste. Biogas is of much lower heating value than the standard fuel oil or natural gas (350 Btu/cft vs. 1,000 Btu/cft). The capability to run on these gases is a distinct advantage of a microturbine over a reciprocating engine. A standard reciprocating gas engine is generally not designed to run on a low Btu gas as this type of gas has a low methane gas content, which provides the primary heating value of a gas. A diesel engine can however run on low Btu gas, but it would require a special design at a high cost. Moreover, NOx emissions from diesel engines are 100 times higher than that from microturbines.

The potential for energy production from biomass throughout the world is enormous, as fossil-based fuels become scarcer and more expensive. Carbon emission levels are becoming a cause of concern. As people realize the benefits of developing integrated energy supply options, biomass could begin to realize its full potential as an energy source. In Europe and the United States, as well as in several developing countries, there is a move toward using biomass as a source of fuel.

The use of biomass for generating electric power is of particular significance to Sri Lanka, Maldives, and essentially the entire South Asia region. Two of the primary biomass products that are available in abundance include rice husk and rice straw. Large quantities of low-Btu gas can be produced from these products with the help of biomass gasifiers. Microturbines are available that can readily use such low-Btu gas.

The economics of burning low-Btu gas is strongly dependent on the cost of converting the biomass into a clean gas. Currently there are many installations in the South Asia region in which biogas is produced from biomass. In these installations, biomass is subject to a gasification process to produce the biogas. Although fuel is renewable and considered ‘free’ in these situations, additional investment would be required to provide for facilities to convert biomass into a gas.

The investment cost of biomass conversion facilities varies over a wide range, depending on the cost of biomass preparation, amount of ash content and cost of its handling, and gas cleaning requirement and its cost. Economy of scale also plays a big role. With these economic considerations and given that there would be no fuel cost, the cost of electricity generation from biomass is expected to be competitive with that from burning natural gas or fuel oil. Technical and economic parameters of a typical biomass-to-electrical energy facility (not for any specific facility) are presented in Table 7-1.

Table 7-1 Technical and Economic Parameters of a Typical Biomass-to-Electrical Energy Facility*

Parameter	Approximate Values	
Type of Biomass	Rice Husk	Rice Straw
Moisture Content	11%	8%
Heating Value	14 MJ/kg (6065 Btu/lb)	17 MJ/kg (7330 Btu/lb)
Ash Content	18%	17%
Production in Sri Lanka in 1994	0.516 Million Tonnes	2.582 Million Tonnes
Electrical Energy Potential	27 Mwe	163 MWe
Heating Value of Biogas	5.58 MJ/m3 to 9.31 MJ/m3 (150 Btu/cft to 250 Btu/cft)	
Installed Cost of Biomass-to-Gas Conversion Facility (Gasifier)	$75/kWt to $100/kWt ($300/kWe to $400/kWe)	
Biomass Consumption	1.3 kg/kWh to 1.6 kg/kWh	
O&M Cost – Biomass-to-Gas Conversion Facility	0.5 US cents/kWt to 0.75 US cents/kWt	
Cost of Electricity from a Biomass-to-Electricity Facility	7.5 US cents/kWh to 8.8 US cents/kWh	

* Source – Ref. 25, Small, Modular Biopower System Based on KC Gasifier Feasibility Study, Bechtel National, Inc., December 1998.

In this section, an order-of-magnitude estimate of total capital investment that would be required if the entire economic market for small scale generation in Sri Lanka and Maldives were to be filled by microturbines using conventional fuel is presented. All cost estimates presented here are preliminary and are based on volume purchase.

Thirty kW and 60 kW are the two sizes of microturbines widely deployed throughout the world with some applications using 70 kW, 80 kW, and 100 kW size units. Installed cost of these units tends to be around $1,200/kW. The 250 kW unit used in the economic analysis in this study is expected to benefit from economy of scale and would cost approximately $1,100/kW.

8.1 Investment Requirement in Sri Lanka

As presented earlier, the economic market size for small on-site generating units in Sri Lanka is about 600 MW. Also, as indicated in Section 6.2, some of this market may be filled by micro-hydro and photovoltaic systems as the country is aggressively pursuing these two generation options. These would leave about a 570 MW market for microturbines.

Based on the economic analysis presented in Section 6, an order-of-magnitude investment requirement is estimated as follows:

- Total capacity installed 570 MW
- Size of each microturbine unit 250 kW (at many sites, multiple units may be installed)
- Total number of units 2,280
- Installed cost per unit $275,000
- Total installed cost $627M

8.2 Investment Requirement in Maldives

As estimated in Section 5.2, the economic market size for small on-site generating units in Maldives is about 10 MW. Based on the economic analysis presented in Section 6, an order-of-magnitude investment requirement is estimated as follows:

- Total capacity installed 10 MW
- Size of each microturbine unit 250 kW (at many sites, multiple units may be installed)
- Total number of units 40
- Installed cost per unit $275,000
- Total installed cost $11M

Even though there is significant potential for microturbines in Sri Lanka and Maldives, there are a number of issues and obstacles facing their deployment (or the deployment of any generating technology). These are briefly discussed below.

9.1 Affordability

Affordability is a major issue in deployment of any generating technology, especially in rural areas. Without a sufficient subsidy or incentive from the government or developer, deployment likely will be difficult and slow. Introduction of micropower would need to be a part of the government's rural electrification program. Developers also would likely need to provide incentives in the form of a reduced price initially in order to develop consumer confidence as well as to penetrate the market.

9.2 Financing

Financing is another major deployment issue. Shortage of affordable and available small-scale financing to cover upfront expenses would make purchasing or leasing a system expensive for most consumers and would be a significant concern.

9.3 Institutional and Policy Issues

Although technological advancements have made microturbines a credible option for on-site generation, there are currently several institutional issues that need to be addressed. These include:

9.3.1 Government Regulations

The potential development of the small-scale power generation market depends on the regulatory policies and market rules developed by central and local regulatory agencies. Some major issues pertain to:

- Siting and permitting
- Interconnection to the grid
- Environmental impacts
- Transmission system scheduling and balancing

9.3.2 Grid Interconnection Issues (For Urban Users)

Interconnection is the linking of on-site generation to the electric utilities' distribution grid (for those who want to remain connected to the grid while generating on-site power). It requires the user and utility to install a variety of relays and monitoring devices on the user's premises and at the connecting distribution lines in order to ensure stability and protection of the grid and protection of the user's site. The complexity and cost of interconnection tend to increase with the magnitude of on-site generation. These costs generally are required to be borne by the user. There are a number of issues related to interconnection to the grid that need to be addressed by regulators and utilities before the on-site power generation market can grow. They include technical issues at the point of interconnection, including:

- Safety issues posed by grid connection
- Distribution system reliability impacts
- Lack of uniform interconnection standards

9.3.3 Utility Tariffs

Tariffs and other charges may alter the economics of on-site generation for those who want to remain connected to the grid while generating on-site power. Two principal types of tariffs could impact the decision to use on-site generation:

- Back-up tariffs, consisting of supplemental and standby charges, can significantly change the economics between grid and on-site generation. Back-up charges that are too high can make it uneconomical for the user to bypass the system.
- Competitive transition charges are charges placed on distribution services to recover utility costs incurred as a result of the user leaving the system (i.e., stranded costs usually associated with generation facilities and services), which are not recoverable in other ways.

9.3.4 Future Electric Utility Policies

Many consumers are wary about government or utility policies that could affect the use of microturbines, because the technology has not been specifically considered within the policymakers' decision making process. Government and utilities policy makers need to clarify these policies up front.

9.4 Acceptance of Microturbines

Internal combustion engines (diesel engines and gas engines) have been in the marketplace for sometime and generally are well known and accepted as an option for small-scale power generation. Extensive consumer education and demonstration of the merits of microturbines over internal combustion engines would be needed. Moreover, maintenance and spare parts facilities as well as operational training facilities would need to be set up by microturbine manufacturers.

9.5 Energy Costs

Energy costs can vary significantly based on factors such as supply and demand, time of year, and location. A relatively low cost of electricity produced by this technology needs to be demonstrated with information from other countries where microturbines are in use.

The conclusions and recommendations outlined here represent the best judgment based on an initial assessment. Detailed studies are recommended for a more accurate assessment. Some conclusions may be expected to change as a result of the more detailed studies.

10.1 Conclusions

An initial estimate of potential economic market for microturbines in Maldives and Sri Lanka has been made. There is a significant market potential for small-capacity, on-site power generation systems in each of the two countries. These systems could be used for base load power supply in rural areas and for emergency/back-up, peak shaving, and quality power supply in urban areas.

The initial estimate presented in this report indicates that the potential current economic market size for microturbines in Sri Lanka could be in excess of 570 MW. The potential current economic market size in Maldives could be as much as 10 MW.

Microturbine is the environmentally preferred technology for small-scale power generation. Existing small-capacity on-site power supply is provided primarily by diesel generating units in both countries. Microturbines have not yet been used due to their relatively recent emergence in commercial markets. Thus, it is difficult to predict how much of the potential market could be realized by microturbines.

10.2 Recommendations

The estimate presented here is only indicative of the size of the market that could be expected. A more accurate estimate and a more reliable investment requirement would require a more detailed assessment of the type and magnitude of power needs of the consumers in each of these countries. This information was not available at the present time especially for industrial and commercial consumers in Sri Lanka. Therefore, it is recommended that a detailed market study be undertaken, which would include the activities outlined in the following paragraphs.

10.2.1 Rural Areas

Many residential areas presently either do not have access to electricity or are not yet electrified. These depend primarily on wood for fuel. This is the largest energy-consuming segment in each country and also has the largest potential market for on-site power generation. One generating unit could serve a number of households with a minimum amount of distribution equipment. As an example, one 30 kW unit would provide electricity to 120 to 130 rural households. The following activities are recommended:

- Conduct a survey of rural areas to identify geographical distribution of residential communities, population distribution, and energy use pattern (energy used per household per year)
- Identify the number of clusters of households and potential sites for on-site power generators

10.2.2 Urban Areas

Residential. Supplying power during peak hours of the day is typically the largest demand in these areas. If power could be supplied at a lower cost, new consumers in these areas could also be a target for base-load power using on-site generation. The following activities are recommended:

- Conduct surveys of urban and estate areas to identify geographical distribution of residential communities and distribution of households
- Evaluate energy use patterns (energy used per household per year, load profile)
- Identify the number of clusters of households and potential sites for on-site power generators

Commercial: Commercial facilities in urban areas could benefit from emergency/back-up and combined cooling, heating, and power supply. This segment represents a large near term potential. Thus this segment should be an initial focus and the following activities are recommended:

- Conduct surveys to identify the number and energy use pattern of the facilities (energy used per facility per year, load profile)
- Evaluate potential emergency/back-up and quality power requirements through surveys

Industrial: Industrial loads have a large market and similar to the commercial segment represent a high near term potential. Typical on-site power requirements would be for peak shaving, emergency/back-up, and combined cooling, heating, and power service. Thus this segment should also be an initial focus and the following activities are recommended:

- Conduct surveys to identify the number and energy use pattern of the various industrial facilities (energy used per facility per year, load profile)
- Evaluate potential emergency/back-up and quality power requirements through surveys

Domestic Fuel Sources: The fuel capability of microturbines is of particular significance to Sri Lanka and potentially to Maldives. Microturbines are available that can readily use low-Btu gas from biomass such as rice husk and rice straw. Large quantities of these rice mill residues are produced in Sri Lanka. Microturbines can utilize this otherwise wasted valuable source of energy for generation of electrical power as well as combined cooling, heating, and power generation with some additional investment. This possibility should be examined thoroughly in both the countries. This application of the technology could be the first step in introducing microturbines.

Deployment Issues. In order to facilitate deployment of microturbines, the governments of Sri Lanka and Maldives need to address a number of the deployment issues, which have been outlined in Section 9 of the report. These issues have varying impacts on the competing technologies and generally affect microturbines to a greater degree than reciprocating engines as the microturbine technology has not yet been utilized in the South Asia region. These issues include:

- Energy cost and affordability

- Financing
- Institutional & Policy including:
  - Government Regulations
  - Grid Connection
  - Utility Tariffs
  - Future Electric Utility Policies
- Market Acceptance

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